

Laboratory 8: Moving Charges and Magnetic Forces

1 Forces Exerted by Magnets on Currents: Qualitative Investigations

Much of this exercise is based on a similar exercise in *Tutorials in Introductory Physics* by McDermott and Shaffer.

- a) A pivoting wire can be connected to an insulating stand and support as illustrated in Fig. 1. The wire is connected to a battery and switch. Connect this circuit **without closing the switch**.
- b) **Predict** (i.e. do not use the apparatus) the direction of the force exerted by the magnet on the wire, provided that the wire is connected to the battery as illustrated and that the switch is closed. Explain your answer.

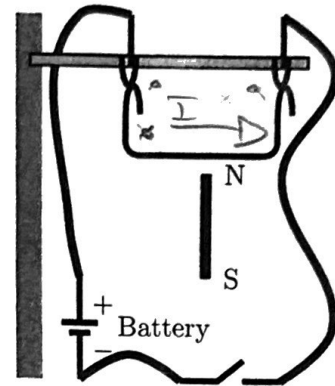


Figure 1: Current and magnet apparatus.

Connect the circuit above and use it to check your prediction. If your prediction was incorrect explain how to correct it.

- c) Suppose that the battery in Fig. 1 was reversed (this can be done by reversing the connections). **Predict** the direction of the force exerted by the magnet on the wire. Explain your answer.

Check your prediction by building the circuit and observing the force. If your prediction was incorrect explain how to correct it.

- d) The circuit is reconnected as before but the magnet is reversed as illustrated in Fig. 2. **Predict** the direction of the force exerted by the magnet on the wire. Explain your answer.

Check your prediction by building the circuit and observing the force. If your prediction was incorrect explain how to correct it.

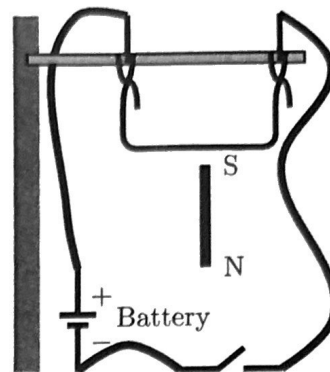


Figure 2: Current and magnet apparatus.

- e) The circuit is connected as before but the magnet is placed parallel to the current as illustrated in Fig. 3. **Predict** the direction of the force exerted by the magnet on the wire. Explain your answer.

Check your prediction by building the circuit and observing the force. If your prediction was incorrect explain how to correct it.

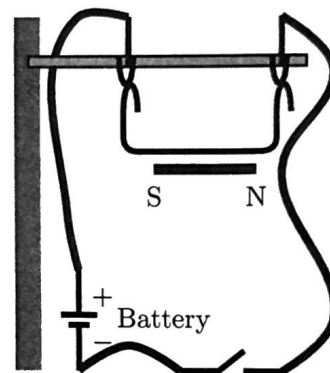


Figure 3: Current and magnet apparatus.

2 Charge to Mass Ratio for an Electron.

Whenever a subatomic particle, such as the electron, has been discovered, an immediate question has been what its charge and mass are. Almost always these questions are partly addressed by firing the particle into a region in which there is a known uniform magnetic field. It emerges that with relatively elementary physics one can easily determine the ratio

$$\frac{\text{particle charge}}{\text{particle mass}}$$

based on the particle trajectory as it passes through the magnetic field. In this experiment you will apply this technique to electrons and will determine the ratio e/m where e is the magnitude of the electron charge and m the electron mass.

In this experiment you will accelerate an electron through a known potential difference. The electron enters a region of approximately uniform magnetic field with its velocity perpendicular to the magnetic field as illustrated in Fig. 4.

- a) Determine the direction of the force exerted by the magnetic field on the electron. Describe the trajectory of the electron (e.g. straight, curved, parabolic, circular, etc, ...).

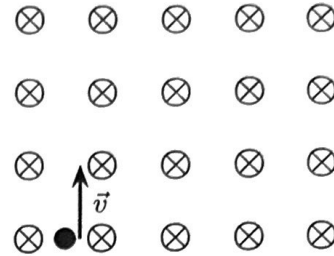


Figure 4: Electron in a magnetic field.

- b) Applying Newton's second law to the situation predicts that the electron will follow a circular path with constant speed. Determine an expression for the magnitude of the magnetic force on the electron and use the dynamics of uniform circular motion to show that

$$\frac{e}{m} = \frac{v}{Br} \quad (1)$$

where v is the electron's speed, r is the orbital radius of the circle and B is the magnitude of the magnetic field.

Unfortunately it will not be possible to measure the electron speed directly; this will be inferred indirectly by knowing the potential difference, ΔV , through which the electron is accelerated prior to undergoing circular motion. The electron is accelerated from rest by applying an electric potential difference to it. Applying conservation of energy to this situation yields

$$\Delta K = e\Delta V \Rightarrow \frac{1}{2}mv^2 = e\Delta V \Rightarrow v^2 = \frac{2e\Delta V}{m}. \quad (2)$$

This suggests rewriting Eq. (1) as

$$\frac{e^2}{m^2} = \frac{v^2}{B^2r^2}. \quad (3)$$

Combining Eqs. (3) and (2) gives

$$\boxed{\frac{e}{m} = \frac{2\Delta V}{B^2r^2}} \quad r = 4.22 \text{ mm} \quad (4)$$

The approximately uniform magnetic field is produced by providing an adjustable and measurable current I through a pair of Helmholtz coils and has magnitude

$$\boxed{B = \frac{\mu_0 8NI}{5\sqrt{5}a}} \quad a = 4.56 \text{ mm} \quad (5)$$

where $\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$, N is the number of turns in each coil, I the current through the coils and a is the radius of the coils. For this apparatus, the number of turns is 130.

- c) Predict what will happen to the electron's path if the current to the Helmholtz coil is increased while the accelerating electric potential difference is held constant.
- d) Predict what will happen to the electron's path if the accelerating electric potential difference is increased while the current to the Helmholtz coil is held constant.
- e) Set up the apparatus so that the accelerating potential difference is between 250 V and 350 V.
- f) Adjust the coil current so that the electrons are deflected in a circle. Keep the accelerating potential difference constant and increase the current through the Helmholtz coils. Observe the radius of the path followed by the electrons. Is this consistent with your prediction? Keep the current through the Helmholtz coils constant and increase the accelerating potential difference. Observe the radius of the path followed by the electrons. Is this consistent with your prediction?
- g) Measure and record the radius of the Helmholtz coils.
- ~~h)~~ Adjust the accelerating potential difference to 250 V. Adjust the Helmholtz coil current so that the radius of the electron path is 4 cm (to the outer edge of the circle). Measure and record the Helmholtz coil current and the accelerating potential difference.
- ~~i)~~ Increase the accelerating potential difference by 20 V and adjust the Helmholtz coil current so that the radius of the electron path is 4 cm. Measure and record the Helmholtz coil current and the accelerating potential difference. Repeat this three more times.
- j) For each value of Helmholtz coil current, compute the magnetic field produced by the Helmholtz coils. Use this and the data for the radius and accelerating potential difference to determine e/m .
- k) Determine the average value for e/m . Express your result in standard scientific form,

$$\frac{e}{m} = \underline{x.xx} \times 10^{\underline{zz}} \text{ units.}$$

How does this compare to the value calculated using the best known values for e and m ?

3 Conclusion

Briefly describe the main finding of the experiment of part 2. When answering this imagine that prior to the experiment no-one knew either the electron charge or its mass.

- b.) The direction of the force should be into the page



- c.) The direction should be out of the page

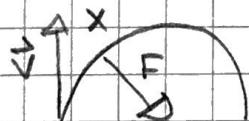


- d.) The direction should be out of the page

- e.) There will be no force since the magnet is parallel.

Part 2

- a.) The direction of the force on the electron is inward on the circular trajectory,



$$b.) F = ma, a = \frac{v^2}{R}$$

$$F = qvB \sin \alpha$$

$$\overset{=e}{q} \overset{=1}{vB \sin \alpha} = m \left(\frac{v^2}{R} \right)$$

$$\cancel{m} \quad \cancel{vB} = \frac{mv^2}{r} \quad \cancel{m}$$

$$\cancel{vB} \quad \frac{e}{m} = \frac{v}{r} \quad \cancel{vB}$$

$$\frac{e}{m} = \frac{v}{rB}$$

$$3 = 4.1$$

$$9 = 4.3$$

✓ 4.1	4.5	4.3	
✓ 4.2	4.4	4.3	
✓ 4.1	4.3	4.2	
✓ 4.1	4.3	4.2	4.22 mm
✓ 4.0	4.4	4.2	
✓ 4.0	4.3	4.15	
✓ 4.1	4.3	4.2	

c) If the current is increased, the path becomes more circular

d) If the potential difference is increased, the radius will increase

f) Both are consistent

g) $a = 14.56 \text{ mm}$
 $r = 4.22 \text{ mm}$

$$\frac{e}{m} = \frac{2\Delta V}{B^2 r^2}$$

$$B = \frac{\mu_0 8 N I}{5 \sqrt{a}}$$

$$B = 1.3 \times 10^{-2} \text{ T}$$

$$\vec{B} = 1.3 \times 10^{-2} \text{ T}$$

$$\Delta V =$$

$$\frac{e}{m} = \frac{2(256.9 \text{ V})}{(1.3 \times 10^{-2} \text{ T})^2 (4.22 \times 10^{-3} \text{ m})^2}$$

$$\frac{e}{m} = 1.61 \times 10^{11} \text{ C/kg}$$

$$\frac{e}{m} = \frac{1.6 \times 10^{-19} \text{ C}}{9.11 \times 10^{-31} \text{ kg}}$$

$$\frac{e}{m} = 1.76 \times 10^{11} \text{ C/kg}$$

$$\% = 8.28\%$$

Part 3)

There's a ratio between the charge of an electron and its mass